14p.

NASA TECHNICAL TRANSLATION NASA TT F-15,308

ECONOMY AND PRACTICAL APPLICATIONS OF LARGE WIND-DRIVEN POWER PLANTS

PART I

H. Witte

(NASA-TT-F-15308) ECONOMY AND PRACTICAL APPLICATIONS OF LARGE WIND-DRIVEN POWER PLANTS, PART 1 (Scientific Translation Service) 14 p HC CSCL 10A

N74-15741

Unclas

G3/03 27970

Translation of: "Über die Wirtschaftlichkeit und Durchführbarkeit von Gross-Windkraftwerken," Elektrotechnische Zeitschrift, Vol. 59, No. 51, December 22, 1938, pp. 1373 - 1376.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON D.C. 20546 FEBRUARY 1974

ECONOMY AND PRACTICAL APPLICATIONS OF LARGE WIND-DRIVEN POWER PLANTS *

PART I

***
/1373

H. Witte **

INTRODUCTION

Recently many projects have been suggested for producing electrical energy on a large scale by taking advantage of the flow energy in our atmosphere. The basic idea is that, on the one hand, our coal reserves are too valuable to be burned up in generating plant fire boxes, and, on the other hand, water generating plants require too much initial investment. This cancels most of the advantage of an energy source which is free.

Except for a few unimportant exceptions, electricity generating companies obtain their energy only from the available water resources, as well as from the oil and coal supplies in the earth. The water resources and the oil and coal resources at first glance seem to be so extensive and inexhaustible, that it might seem useless to be developing other types of energy sources for producing the required electricity. As far as the water resources

* Paper presented at the VDE Section, Berlin-Brandenbürg Meeting on (illegible). No discussions were held.

** VDE, Berlin, Germany

*** Numbers in the margin indicate pagination of original foreign text.

are concerned, in countries in which there is abundant water with substantial altitude variations it will be difficult to make the decision to select another type of energy for producing electrical energy. On the other hand, in Germany, in spite of extensive projects for exploiting our water energy, one does not gain the impression that it would be advisable to become too dependent on the water energy. According to the latest drilling results, we still have enormous coal reserves in the form of brown coal and stone coal which will provide an ample supply of energy over a long time period. It would not be necessary to consider other types of energy because our coal reserves are ample for electricity production. However, over the last few years it has been established, particularly in the period after the war, that coal is one of our most valuable and purest commodities and therefore represents a substantial part of the wealth of our people. The chemical compounds contained in the coal, first of all the hydrocarbon compounds, are so important for our overall economy that wherever possible we should not be burning it up in fire boxes. Therefore, it is not the scarcity but the valuable content of coal which makes it advisable to prefer any other type of energy for producing electricity. This must be done under the condition that the electricity will be produced economically.

These and similar reasons have always been the basis for exploring new natural forces for producing electrical energy. The wind energy has never been the most important such energy source. Instead, more effort has been devoted to harnessing the tides [1]. Other researchers have attempted to take advantage of the sun's radiation, but this has resulted in only a few kilowatts using very large and expensive installations. The most uneconomical generating station is probably the one located on the coast of Cuba, where the temperature differences of the ocean between the surface and at considerable depths will be exploited [2]. At a cost of about two million dollars, believe it or not, a power output of about 20 kW was achieved.

Enormous sums were expended for these experiments, without having previously taken the effort of thinking through and calculating the designs down to the last detail. The related failures explained why specialists have a great deal of apprehension when confronted with all projects connected with the exploitation of wind energy. Unfortunately this apprehension has been intensified because the press in magazines and even in technical articles again and again publish accounts in the area of electrical power generation by wind energy. The public is led to believe that the associated "energy production costs" will be so low that an overall reduction in utility costs will be brought about. Nothing could be further from the truth.

WIND CONDITIONS IN GERMANY

Let us first consider research conducted up to the present regarding the wind conditions and their variation. We can see that relatively little work has been done in this area, especially as applied to the generation of electrical power by wind energy. There have been extensive investigations of wind frequency, wind /1374 intensity, wind direction, etc. but the purpose of these investigations was usually to expand our knowledge of nature, so as to serve agriculture, shipping, etc. Observations were always made just above the ground or only at small altitudes.

This changed immediately when it became necessary to examine the wind conditions more closely to satisfy the needs of aviation. At the same time, it became apparent that knowledge about the motion of air at large altitudes above the Earth's surface was extremely scanty and that this gap had to be filled immediately. Professor Assmann was the director of the "aeronautical observatory" in Lindenberg and occupied himself with these problems between the years 1907-1910. He published the first major book entitled "The Winds in Germany" based on over one million individual observations made at altitudes between 40 and 120 m. One of his most important findings for the problem under discussion here is that in Germany there are several wind zones which differ greatly from each other. These zones are the North Sea coast, the East Sea coast, Central Northern Germany, Southern Central Germany — in particular, Harz and Thuringia — Southwest Germany and Southeast Germany. The differences between these zones is primarily due to the fact that the wind intensities are considerably different from each other. In the North German regions the wind intensities are higher than in our area, which is one of the extensive areas with low winds intensity. The individual zones also differ in the variation of equal wind intensities over time. For example, when there are strong winds along the North Sea coast, and there will probably be weak winds along the East Sea coast. The Brocken, the Peninsula Hela and the Island of Borkum and their surroundings are areas with extremely high wind intensities.

Just before the war and during the war, Professor Hellmann of the Reichs Weather Service made a detailed analysis of wind flows. He was one of the first to also consider wind conditions at large distances from the Earth's surface. The results were important for two reasons and for the possible exploitation of wind energy for producing electrical energy.

He first determined that the lower air layers up to an altitude of about 80 m from the Earth's surface moved a minimum amount at night and a maximum amount at noon. This air layer, within which the wind directions and wind intensities cannot be calculated at all because of the frequent and sudden changes, is least powerful over flat land. The power increases when it moves over uneven terrain. Therefore it is not correct to assume that low generating plant heights can be used on low hills which rise out of the flat land. In contrast to this idea, the ground winds follow the ground formations quite accurately. Over rough terrain, vortices are formed which are very unfavorable for wind energy generation plants. In order to overcome the zones with weak winds and large changes, and in order to obtain the smallest building heights, the sites must be selected in extensive flat regions.

It was also determined that the wind velocities increase considerably with distance from the Earth. The flow velocity and direction become more uniform at the higher altitudes. The daily variation mentioned above also exists at large distances from the Earth. However, conditions are reversed because the maximum occurs at night and the minimum occurs at noon. (Figure 1). Other scientists, such as Bongards, Spitaler, Barkow, etc., who dealt with this problem reached similar conclusions.

The lower air layer mentioned above, that is the layer between the ground up to a height of about 80 meters, is called the "Earth vortex zone" because of the fact that the wind flows cannot be calculated. This term probably gives a good description of the fact that there are substantial changes in wind direction and velocity within this layer. Horizontal vortices and vertical vortices occur. Gusts occur, of course, at all altitudes above the ground and they gradually decrease at about 2,000 m. They are quite powerful and erratic at the higher levels. At the higher levels, they are smoother and are not as strong as compared with the prevailing average wind intensity.

Once research on wind conditions at the higher altitudes had begun, very soon additional measurements were made. These showed that an altitudes above 200 m, the wind flows are uniform to a high degree. The direction cannot be influenced much by obstacles. The observations at the 300 m high Eiffel Tower as well as on the Nauen Radio Tower (285 m) were carried out over several years (see Figure 2). The results showed that the wind flows were relatively uniform. At the same time this resulted in valuable information on the wind intensities at large altitudes. The wind velocity was found to vary between 7 and 10 m/sec on the average. Up to now we have only talked about average phenomena /1375 and average values. In dealing with the question of whether wind flows are suitable for producing electrical energy, we are not so much concerned with the average values but instead with the actual wind frequencies. The limiting values are of particular interest, i.e., the absolute no-wind conditions and the periods of low wind velocities, as well as the storms and hurricanes. Average values can conceal these maximum and minimum values, which are extremely important for electrical power production.

A few tables, the oldest of which is due to Assmann, will answer the question of the actual frequency of the various wind intensities. The data of Assmann was then used by Betz, Göttingen, to produce a wind frequency table for a large number of locations. Recently these tables have been used by many researchers.

This table shows that low wind velocities, i.e., velocities up to 5-m/sec, are extremely frequent not too far from the ground. These winds make up over 50% of all observations with the exception of the Brocken. The Brocken area is within Germany completely different from all other average test results and will probably be the most advantageous area for exploiting the

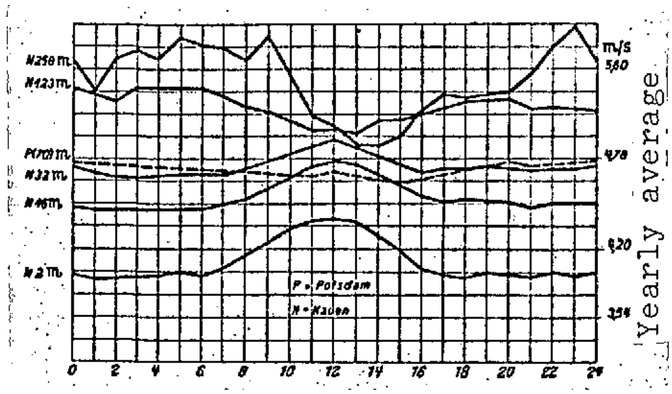

Figure 1. Daily variation of winds, according to Hellmann.

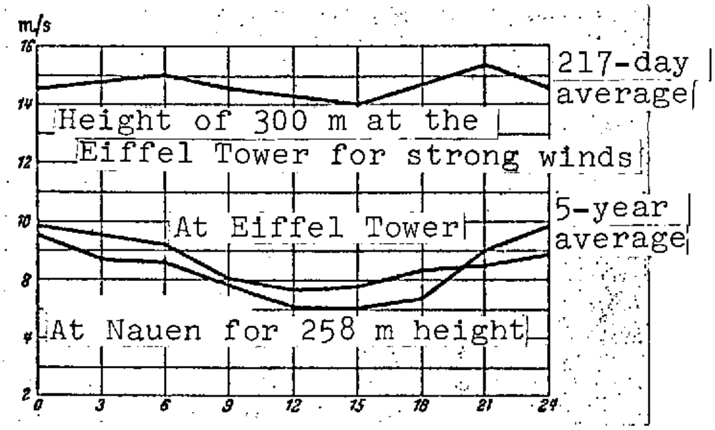

Figure 2. Average values for the Eiffel Tower and at Nauen.

wind for electrical energy production. We even found weaker winds on the Schneekoppe.

Some reservations have been expressed regarding the data on winds collected at high altitudes. These reservations will probably disappear because of the publication of an extensive investigation of the Reichs Weather Service (Figure 3). About 30,000 individual observations were made over several years. It has been established that the numerical series based on earlier experiments result in values which are too low. The experiments of the Reichs Weather Service were carried out at various locations in Central Germany and apply for an area which includes Vorpommern Mecklenburg, Brandenburg, Thüringia and Saxonia. Assuming an average ground height of 100 meters above sea level, the observations were made at approximate altitudes between 500 - 900 meters above the surface of the ground. There are noticeable differences with respect to the data of Assmann. There are almost no very weak winds, and over 75% of the data represents wind intensities which can be exploited. The test results of the Reichs Weather Service were done with carefully controlled conditions. Therefore the data shows wind frequencies which are quite favorable for the economy of wind generating stations.

We may make the following statements regarding the overall wind conditions in Germany: there are several wind regions and the wind intensities of these regions complement each other to a significant degree. The wind velocities increase very rapidly with increasing distance from the Earth's surface. The wind flows are very unreliable in a layer up to a distance of 80 meters from the Earth's surface on the average, the so-called "Earth vortex zone". The direction and intensity of the wind change very rapidly. Vortices and sometimes gusts are formed. At high altitudes, there is only a small tendency towards sudden changes in direction and intensity. The average wind intensity is 9 - 10 meters at an altitude of 400 - 600 m. Gusts do occur but they are softer and not as dangerous. No wind conditions are very rarely encountered.

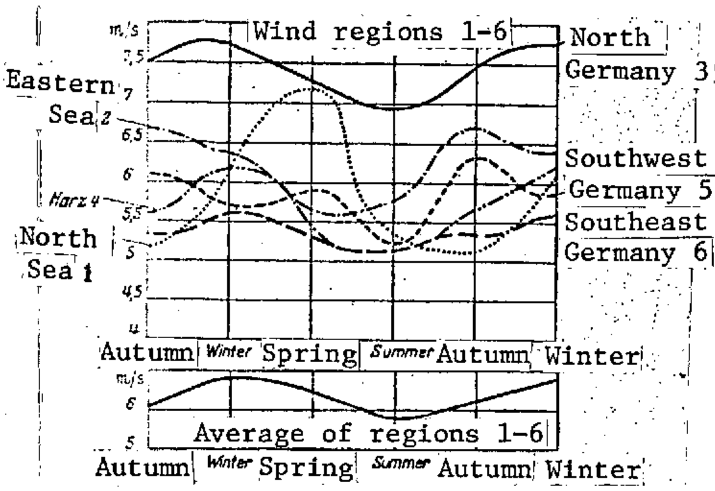

Figure 3. Wind intensity in the six wind regions and the average values.

ECONOMY OF THE WIND ELECTRICAL GENERATING STATIONS

In order to calculate the maximum power which can be produced by wind turbines from wind energy, the following equation is used

$$L_{max} = \frac{v^3}{27} \frac{D^2 \pi}{4} \text{ in mkg/s.}$$

In this equation, D is the diameter of the wind fan blade and v is the wind velocity. This means that the power increases with the square of the fan diameter and the third power of the wind velocity. It should be noted that the wind wheel can theoretically exploit a maximum of 60% of the energy contained in the wind. In the following we will set this maximum power level equal to 100%. Depending on the construction of the wind wheel, efficiency losses amounting to between 20 and 30% occur. In addition there are the efficiency coefficient losses of the force transmission units and the generator. Table 1 shows the maximum power levels assuming a total efficiency of 0.65.

NUMERICAL TABLE 1. *

MAXIMUM POWER IN kW FOR A TOTAL EFFICIENCY OF 0.65

Wind velocity in m/sec	Wind wheel diameter in m					
	20	40	50	100	120	160
2	0,64	2,56	4	16	23,2	40,8
4	5,12	20,5	32	128	186	326
6	17,28	70	108	432	626	1 100
8	41	164	256	1 024	1 485	2 610
10	80	320	500	2 000	2 900	5 100
12	138	550	864	3 456	5 010	8 800
15	270	1080	1685	6 740	9 770	17 185
20	640	2560	4000	16 000	23 200	41 000

* Translator's note: Commas in numbers represent decimal points.

The numbers show that when there are weak winds, there is no significant power production at all. Even for an enormous wheel diameter of 160 m, as has been suggested by many designers, only 326 kW is produced for a wind velocity of 4 m/sec. Because of the extremely steep growth of the performance curve, it is possible to obtain significant power levels for average wind velocities, especially when the propellor diameter is very large. For a wind wheel diameter of 50 m and a wind velocity of 50 m/sec, for example, about 1,685 kW is produced. Already 17,000 kW is produced for the same wind velocity and a diameter of 160 m. If the wind velocity increases above 15 m/sec, all designers which can be taken seriously provide devices which avoid a further increase in the rotation rate and therefore a further increase in the power level. In this case the axial thrust becomes so large that the forces produced can only be controlled with difficulty.

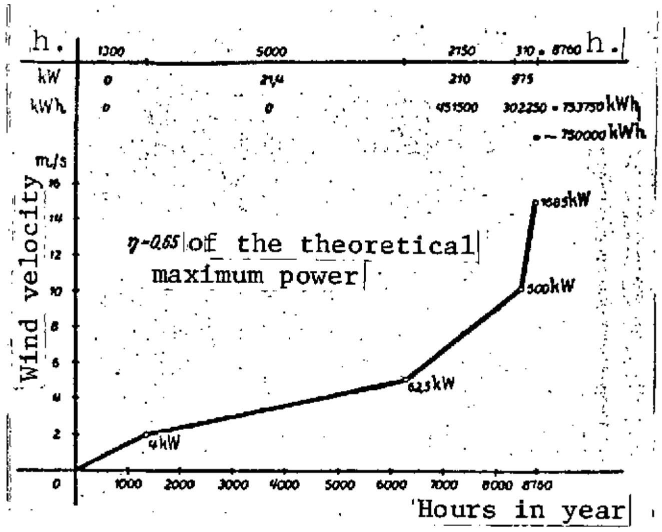

Figure 4. Maximum current production for a wind wheel diameter of 50 m

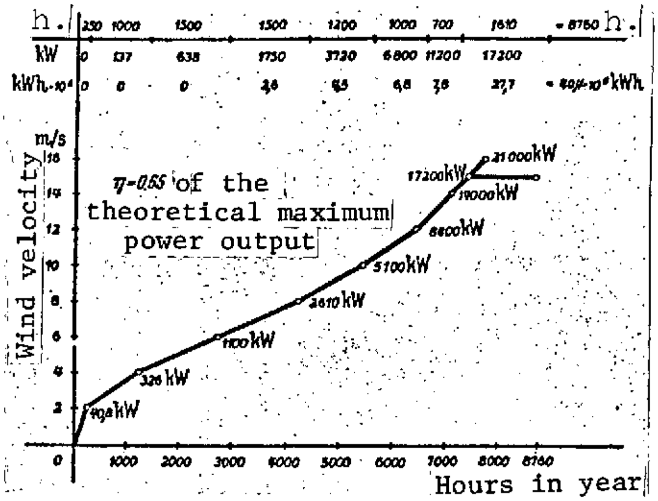

Figure 5. Maximum current production for a wind wheel diameter of 160 m.

Based on this table and the numerical data given above on wind frequencies, it is possible to compute the electrical power which could be produced using a wind wheel. We will only discuss two examples in detail: /1376

In the first example we consider a generating station with a height of about 100 m and an installed power level of 2,000 kW. The wind wheel diameter is 50 m, and the efficiency is 0.65. The location is in Central North Germany. The curve shown in Figure 4 is obtained based on the calculated power levels for this wind wheel diameter and for various wind velocities. The wind frequencies given by Betz have been used. Since the wind turbine only begins to move at a wind velocity of about 2m, first of all 1,300 hours cannot be used at all for electrical energy production. Over the next 5,000 hours of the year, the wind velocities vary between 2 and 5 meters which corresponds to an average power level of 21.4 kW. Even a very optimistic critic of wind power generating plants would have to admit that such a power level cannot be used at all to transmit power to third persons. This is because this power is used to satisfy the power requirements of the station itself and is not even enough to excite the generator. This means that at best, the remaining 2,460 hours of the year can be used for giving off power to third parties. This occurs at an average power level of 210 kW for the range 5 - 10 m/sec and 975 kW for the range 10 - 15 m/sec. The total amount of work available over the entire year amounts to about 3/4 million kWh. Based on an installed power level of 2,000 kW, this amounts to an operational time period of 375 hours. We will discuss below the meaning of this for the production costs.

Another example: Let us assume a power generating station has a height of 500 m, a wind wheel diameter of 160 m and an installed power level of 20,000 kW. Let us assume that the efficiency and location are the same as in the first example. Considering the wind frequencies established by the Reichs Weather Service for such altitudes, we find the curve shown in Figure 5. Up to 4 m/sec wind velocity, the produced power level is so small that it can be set equal to zero. Up to 6 m/sec wind velocity there is an average power level of 638 kW, which, however, will still be ignored. Above 15 m/sec wind velocity it is assumed that there is no further increase in the power level. Instead it is assumed that devices are available to prevent a further increase in the rotation rate. The sum of the electrical work produced which must be considered amounts to approximately 50 million kWh. Based on the installed power level, this results into an operational period of about 2,500 hours.

Examples discussed above show clearly that if a wind power generating plant is to give off power to third parties, it will only be economical if the installed power levels are very high.

It only makes sense to install such high power levels if the stronger and more uniform wind flows at high altitudes can be exploited (conclusion follows).

REFERENCES

1. Elektrotechnische Zeitschrift, ETZ, Vol. 48, 1927, p. 831; ETZ, Vol. 52, 1931, pp. 360 and 639.

2. ETZ, Vol. 53, 1931, p. 1477.

Translated for National Aeronautics and Space Administration under contract No. NASw 2483, by SCITRAN, P.O. Box 5456, Santa Barbara, California, 93108

STANDARD TITLE PAGE

1. Report No. NASA TT F 15,308	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ECONOMY AND PRACTICAL APPLICATIONS OF LARGE WIND-DRIVEN POWER PLANTS PART I		5. Report Date February, 1974
		6. Performing Organization Code
7. Author(s) H. Witte		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw-2483
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of: "Über die Wirtschaftlichkeit und Durchführbarkeit von Gross-Windkraftwerken". Elektrotechnische Zeitschrift, Vol. 59, No. 51, Dec. 22, 1938, pp. 1373 - 1376.

16. Abstract

The question of the economy of large scale wind electrical generating stations is investigated based on present findings. By exploiting wind energy for producing electrical power, large amounts of coal could be made available for other uses, and would also ease our foreign currency situation. The practical aspects of large scale wind electrical power generating plants are discussed. The construction of a ring generator is described.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages ~~13~~ 14	22. P...